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Dust at sub-solar metallicity: the case of post-AGB stars in the Large Magellanic Cloud

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Abstract. Low- and intermediate-mass stars are one of the important dust sources in the interstellar medium (ISM) of galaxies. The compositions of dust ejected from these stars are likely to affect those in the ISM. We investigate dust in post-Asymptotic Giant Branch (AGB) stars, which are in a late evolutionary phase for low- and intermediate-mass stars, and which produce a wide variety of dust grains. We are particularly targeting post-AGB stars in the Large Magellanic Cloud (LMC), which has about half of the solar metallicity, to investigate the effects of sub-solar metallicity on dust compositions.

Using the Spitzer Space Telescope, we obtained 5–30 μm spectra of 24 post-AGB candidates in the LMC. Five are C-rich post-AGB stars, and this presentation focuses on spectra of these stars.

We found that rare dust features in the Milky Way, such as a 21 μm unidentified feature are commonly found in LMC post-AGB stars. The 6–8 μm spectra are compared with those of Galactic objects. Four spectra match the Galactic templates of polycyclic aromatic hydrocarbon (PAH) features. However, we found the three objects show 7.85 μm feature which have not found in Galactic post-AGB stars. Low metallicity conditions definitely affect the dust formation process and compositions.

1. Introduction

There are four key aspects regarding dust grains to be investigated in AGB stars, post-AGB stars and planetary nebulae (PNe). First, the dust grains maintain the thermal balance within the nebulae, absorbing UV and optical photons, and sometimes producing large infrared excesses (Kwok 2000). Second, dust grains are an important catalyst for molecular formation. In particular, chemical reactions on grains are re-

quired to produce molecular hydrogen (Hollenbach & Salpeter 1971), including in PNe (Aleman & Gruenwald 2004; van Hoof et al. 2010). Third, dusty disks and tori might trigger asymmetry in post-AGB stars and PNe. Finally, these evolved stars are one of the important contributors of dust found in the interstellar medium (ISM) of galaxies (Gehrz 1989; Matsuura et al. 2009). The importance of dust is reported in the White Paper developed during this conference.

Our work is specifically directed to comparing dust found in circumstellar envelopes (CSEs) of AGB/post-AGB/PNe to the dust in the ISM. As such, we will be able to reveal if dust has been subsequently processed in the ISM. Our main focus is the dust in post-AGB stars, where wide varieties of dust species have been detected.

Our targets are post-AGB stars in the Large Magellanic Cloud (LMC), our neighbouring galaxy. One of the advantages is that the distance of post-AGB stars in this galaxy are independently measured, whereas the distance is an unknown parameter for the Galactic post-AGB stars. This is ideal since it allows one to trace the stellar evolution on an HR diagram. Secondly, the LMC provides a laboratory at sub-solar metallicity. Dust grains contain metals and so the mass and composition of dust might change according to the metallicity. Finally, the close distance is favourable for resolving the constituent stars in the galaxy, and recent advances in observational techniques in the infrared enable us to carry out detailed studies of objects belonging to this galaxy for the first time.

In this paper, we report our observational studies of dust in the LMC, indicating the effects of metallicity on the dust grains in the post-AGB stars.

2. Observations

We have obtained spectra of 24 post-AGB candidates in the LMC, using the Infrared Spectrometer (IRS; Houck et al. 2004) on board the Spitzer Space Telescope. We used the low-spectral resolution mode for the majority of targets. The spectral resolution was $\lambda/\Delta\lambda=60-130$. We have chosen the targets largely based on infrared brightness, using the Spitzer imaging survey data of the LMC (SAGE; Meixner et al. 2006). Matsuura et al. (2011) describe the details of the sample selection and provide an observing log.

Mid-infrared spectroscopy is a powerful tool to distinguish object types (AGB, post-AGB, PNe, and R CrB) of infrared-bright evolved stars, as well as chemical types (oxygen-rich or carbon-rich; no obvious S-type stars found). Figure 1 shows the spectra of the 24 targets we observed. We describe the characteristics and categorise post-AGB objects in our paper; we found 5 carbon-rich (hereafter, C-rich) post-AGB stars and 2 oxygen-rich (O-rich) post-AGB stars. Other types we found among our sample were 8 C-rich AGB stars, 2 R CrB candidates, 3 C-rich PNe, 3 young stellar objects (YSOs) and 1 luminous blue variable (LBV). Among our sample, there are no O-rich AGB stars.

The largest category in our sample is C-rich AGB stars. The stars we detected are special amongst C-rich AGB stars, the so-called ‘extremely red objects’ (EROs) (Gruendl et al. 2008). The spectral energy distributions peak in the $10-20\mu\text{m}$ range, often with a SiC dust feature at $11.3\mu\text{m}$ in absorption. C-rich stars commonly show C_2H_2 in absorption (Matsuura et al. 2006). EROs still show C_2H_2 in absorption, but very weakly. Some of them (e.g. IRAS 05189–7008 in Figure 1) have a secondary peak in the optical, showing that the central star has partially cleared out its optically-

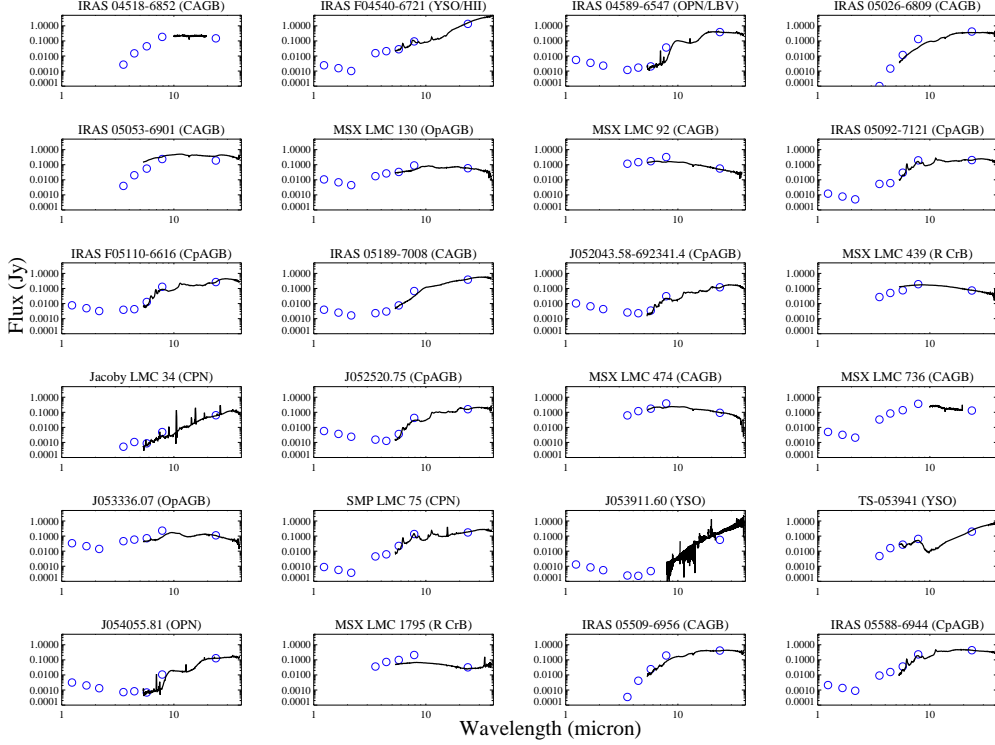


Figure 1. Spitzer IRS spectra of LMC IR bright objects, overlaid on photometric data at 1–24 μm . Object classifications show CAGB (C-rich AGB), CPN (C-rich PN), CpAGB (C-rich post-AGB), LBV (luminous blue variable), OPN (O-rich PN), OpAGB (O-rich post-AGB), R CrB, YSO (young stellar object).

thick circumstellar envelope. It is likely that these stars are transiting from the AGB to the post-AGB phase.

Gielen et al. (2009) and van Aarle et al. (2009) have studied post-AGB stars in the LMC, and their targets are mostly binary objects. They found more to be O-rich than C-rich. Our targets are not selected based on suspected binarity. Although the samples are small, it is possible that binarity and chemical types may be related.

3. Dust features in C-rich post-AGB stars

Figure 2 present the Spitzer *IRS* spectra of the five C-rich post-AGB stars, showing a variety of emission features. The next section discusses the features related to PAHs, which dominate. The 30 μm feature probably arises from MgS (Goebel & Moseley 1985). The features at 6.9 μm and 7.3 μm are likely to be from aliphatic carbon (Duley & Williams 1981; Kwok et al. 2001), although there might be some contributions of PAHs to the 6.9 μm feature (Tielens 2008).

The spectra in Figure 2 also show a feature centred at 15.8 μm (e.g. IRAS 05092 and J052520.70) and the unidentified ‘21 μm ’ feature, which actually peaks at 20 μm in these spectra. The carrier of 21- μm feature remains a point of controversy (e.g. Volk et al. 1999; Hrivnak et al. 2009). The details of this feature in our sample will be

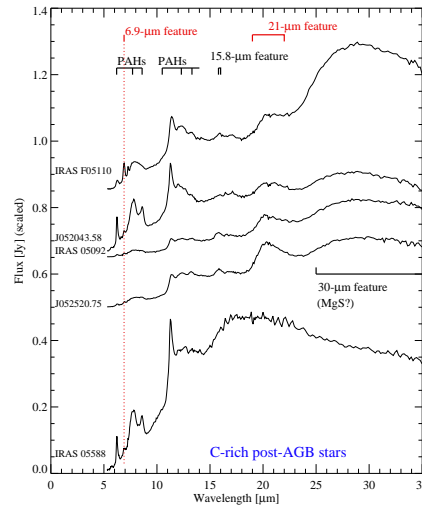


Figure 2. Spectra of C-rich post-AGB stars in the LMC.

presented by Volk et al. (2011). The carrier of the $15.8\mu\text{m}$ and $21\mu\text{m}$ features may be related (Hrivnak et al. 2009; Zhang et al. 2010).

4. Polycyclic Aromatic Hydrocarbons (PAHs) and other features at 6–9 μm

To examine the details of PAH features and other small features, we subtract ‘continua’ from the observed spectra. Matsuura et al. (2011) provide details of this process. Figure 3 plots the continuum-subtracted spectra. Peeters et al. (2002) and Hony et al. (2002) have analysed PAHs in Galactic objects, including post-AGB stars, PNe, and HII regions, and these authors classified them into classes, A, B and C. Figure 3 shows their template spectra. The classes can be distinguished by the number of peaks and the peak wavelength, as indicated in the figure. Both classes A and B show features peaking at about $7.65\mu\text{m}$ and $7.85\mu\text{m}$, with the $7.65\mu\text{m}$ peak dominating in class A and the $7.85\mu\text{m}$ peak dominating in class B. In class C, only a single peak appears at about $8.3\mu\text{m}$.

Among our sample, two spectra can be classified into A, and another two into B. Three further objects show similar profiles to class C, as they have a broad single feature between 7 and $9\mu\text{m}$. However, their peak wavelengths are shorter than those found in class C. These three spectra do not fit within the current A-B-C classification system. We label these three as ‘others’, having two peaks at about 6.3 and $7.85\mu\text{m}$.

In the spectra of these three ‘others’, the $6.3\mu\text{m}$ feature is due to PAHs. However, the feature of these three others is broader than normally observed, and it much more symmetric. Overall, the behaviour of this feature is analogous to the behaviour of $7\text{--}9\mu\text{m}$ feature, and together these suggest a carrier that differs in some way from a normal PAH mixture.

The $7.7\text{--}7.8\mu\text{m}$ feature could arise from PAHs (Sandford et al. 1998a,b) or the vibrational transition of $-(\text{CH}_2)_n-$ in aliphatic carbon (Socrates 2001). However, the width

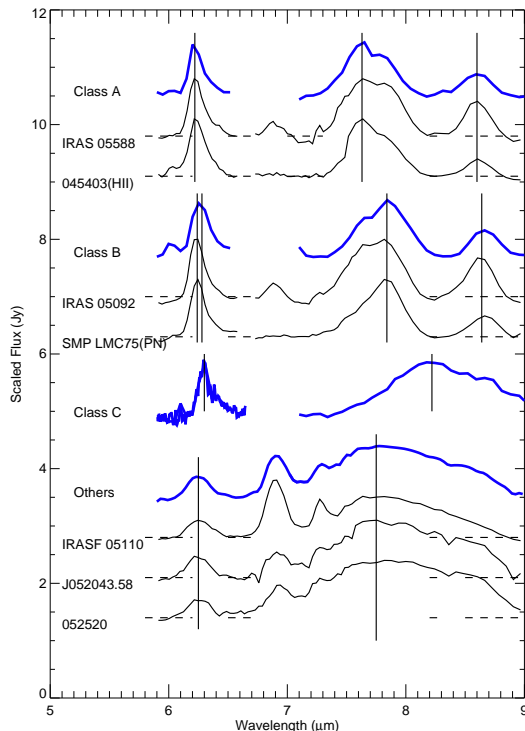


Figure 3. The 6–9 μm spectra in LMC post-AGB stars. As references, PAH spectra of an HII region and planetary nebula in the LMC are plotted. Peeters et al. (2002) and Hony et al. (2002) have analysed PAHs in Galactic objects and classified them into three classes, A, B and C, and we plot these templates. The spectra of the three LMC objects match any of the Peeters classes. These three are called 'others'.

of the feature probably requires multiple components rather than a solitary aliphatic-carbon band.

Although Galactic class C and LMC the 7.85 μm feature objects have central stars with similar spectral types (F and G; Peeters et al. 2002; Sloan et al. 2007), the features appear at slightly different wavelengths. It could be due to the difference of PAH compositions between LMC and Galactic objects. Whereas in class A and B PAHs, there is no difference between LMC and Galactic objects. The difference is found only in stars with spectral classes of F and G-type.

Among C-rich post-AGB stars, we did not find any difference in the strength of PAHs between Galactic and LMC objects. This is consistent with what Bernard-Salas et al. (2009) found in PNe. Among objects with 21 μm features, which are a sub-class of post-AGB stars, PAHs are stronger (Volk et al. 2011). At lower metallicity, PAHs could be formed reasonably well. This is because C_2H_2 , which is a parent molecule for the PAH formation (Allamandola et al. 1989), is abundantly found in AGB stars in lower metallicity galaxies (Matsuura et al. 2005, 2007; Sloan et al. 2009) since carbon atoms are synthesised within these stars and since the oxygen abundance is low, resulting in a high excess of available carbon.

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